RESERVE
COLLECTION

FEASIBILITY REPORT
ON USE OF
RICHMOND-SAN RAFAEL BRIDGE
FOR RAPID TRANSIT

JANUARY 1965

STATE OF CALIFORNIA · HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS · DIVISION OF BAY TOLL CROSSINGS

F CALIFORNIA EDMUND G. BROWN, Governor

WAY TRANSPORTATION AGENCY
ENTO

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DOCUMENTS
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January 8, 1965

Honorable Joseph A. Beek
Secretary of the Senate
State Capitol
Sacramento, California

Dear Mr. Beek:

In accordance with Chapter 118, Statutes of 1964, requiring a report be submitted to the Legislature by the fifth day of the 1965 Legislative Session, it is my pleasure to submit to you a report titled "Feasibility Report on Use of Richmond-San Rafael Bridge for Rapid Transit". The report was prepared by the Division of Bay Toll Crossings, Department of Public Works.

I concur in the conclusions and recommendations made in the report.

Respectfully submitted,

Robert B. Bradford

ROBERT B. BRADFORD
Administrator
Highway Transportation Agency

Enclosure

CALIFORNIA
EDMUND G. BROWN, Governor
VAY TRANSPORTATION AGENCY
NTO

January 8, 1965

Honorable James D. Driscoll
Chief Clerk of the Assembly
State Capitol
Sacramento, California

Dear Mr. Driscoll:

In accordance with Chapter 118, Statutes of 1964, requiring a report be submitted to the Legislature by the fifth day of the 1965 Legislative Session, it is my pleasure to submit to you a report titled "Feasibility Report on Use of Richmond-San Rafael Bridge for Rapid Transit". The report was prepared by the Division of Bay Toll Crossings, Department of Public Works.

I concur in the conclusions and recommendations made in the report.

Respectfully submitted,

Robert B. Bradford

ROBERT B. BRADFORD
Administrator
Highway Transportation Agency

Enclosure

F CALIFORNIA—HIGHWAY TRANSPORTATION AGENCY
EDMUND G. BROWN, *Governor*

RTMENT OF PUBLIC WORKS
NTO

January 8, 1965

Honorable Robert B. Bradford
Administrator
Highway Transportation Agency
Sacramento, California

Dear Sir:

Transmitted herewith is a report by the Division of Bay Toll Crossings prepared pursuant to Chapter 118, Statutes of 1964, regarding the installation of rapid transit facilities on the Richmond-San Rafael Bridge.

The results of the investigation conclude that it is not feasible to use the Richmond-San Rafael Bridge for rapid transit purposes.

I concur in the findings and recommendations of the report.

Respectfully submitted,

JOHN ERRECA
Director of Public Works

Enclosure

ALIFORNIA—HIGHWAY TRANSPORTATION AGENCY
EDMUND G. BROWN, Governor

T OF PUBLIC WORKS
N OF BAY TOLL CROSSINGS
NT STREET
ISCO, CALIFORNIA 94105

Honorable John Erreca
Director of Public Works
Sacramento, California

Dear Sir:

Chapter 118, Statutes of 1964, appropriated the sum of $12,000 to investigate the feasibility of placing rapid transit facilities on the Richmond-San Rafael Bridge.

Transmitted herewith is a report titled "Feasibility Report on Use of Richmond-San Rafael Bridge for Rapid Transit" prepared by the Division of Bay Toll Crossings pursuant to your directive of July 6, 1964.

Due to the overstresses which would be caused in the main supporting members of the bridge, the extreme cost and doubtful practicability of remodeling and the contractual obligations to the outstanding bond holders, it is recommended the Richmond-San Rafael Bridge not be used for rapid transit purposes.

Respectfully submitted,

E R Foley

E. R. FOLEY
Chief Engineer

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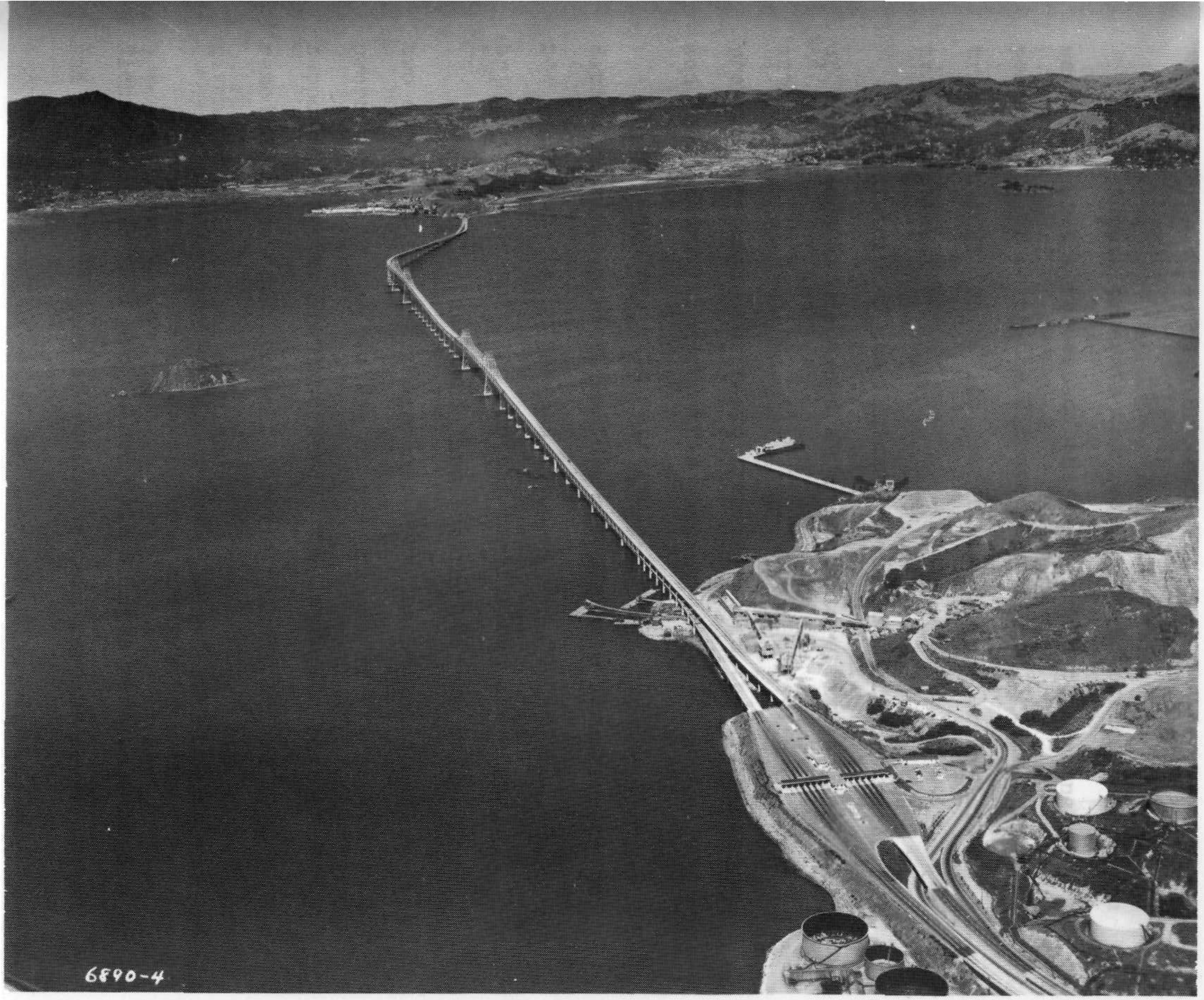
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I SUMMARY

This report presents the results of investigations which were made at the request of the legislature concerning the possibility of using the Richmond-San Rafael Bridge for rapid transit in addition to its present use for motor vehicle transportation.

The history of the financing, design, and construction of the bridge is discussed along with its estimated and actual traffic service. Also included is a review of the previous proposals for rapid transit routes to Marin County and the authorization for this present study.

After meetings with representatives of the Bay Area Rapid Transit District (BARTD), all possible arrangements of the tracks on the bridge and the approach connections to the bridge were investigated and the conclusions are stated.

The modified dead and live loadings of the bridge for two different track arrangements were investigated and the overstresses in the members of the trusses of the main supporting system are tabulated. The estimated cost of remodeling the deck system for rapid transit tracks is given to indicate its magnitude.

The traffic diversions to rapid transit from the Richmond-San Rafael and Golden Gate Bridges were estimated and the resulting loss of vehicular toll revenue is estimated.

The legal obligations of the California Toll Bridge Authority to the present bond holders of the bridge are stated.

Briefly the conclusions of this report are:

1. There are only two possible arrangements of the rapid transit tracks on the bridge which justified a structural analysis.

2. The structural analysis showed that in both arrangements the resulting factors of safety for the main truss systems would be below the minimum allowable.

3. The estimated rapid transit patronage would divert 1,450 vehicles per day from the Richmond-San Rafael Bridge in 1965 and 2,700 in 1980.

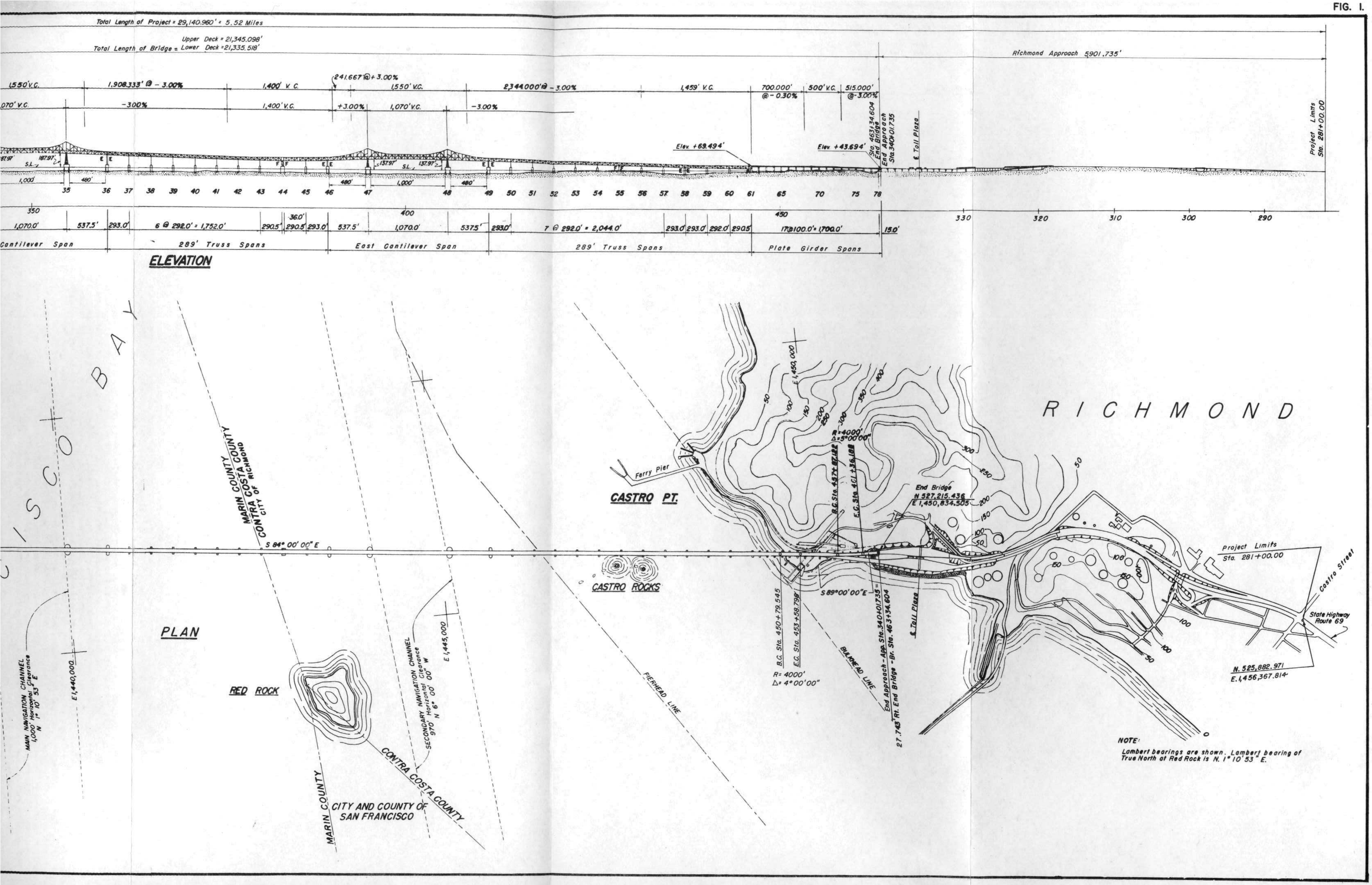
4. A rapid transit system on the Richmond-San Rafael Bridge would divert only 3,100 vehicles per day from the Golden Gate Bridge in 1965. This relief amounts to less than one year of anticipated growth.

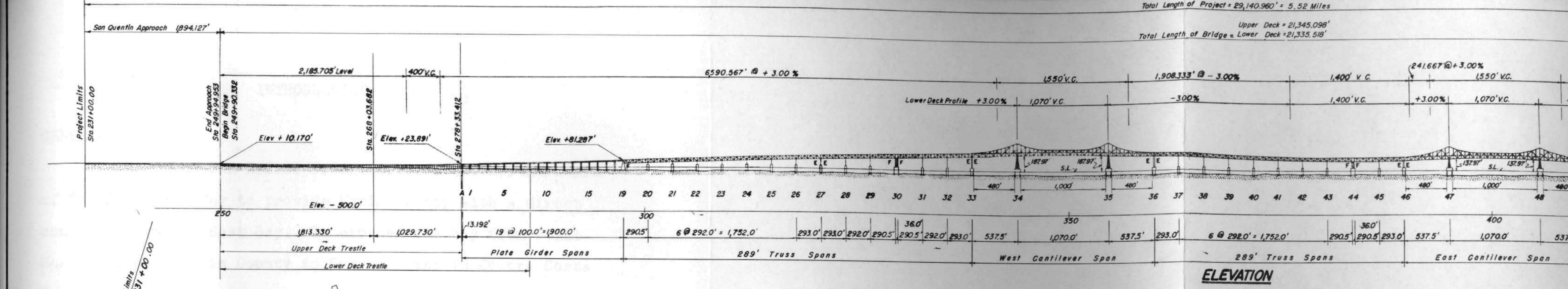
5. The California Toll Bridge Authority, under the terms of its existing bond indenture, cannot finance the installation of rapid transit facilities on the Richmond-San Rafael Bridge.

RECOMMENDATION

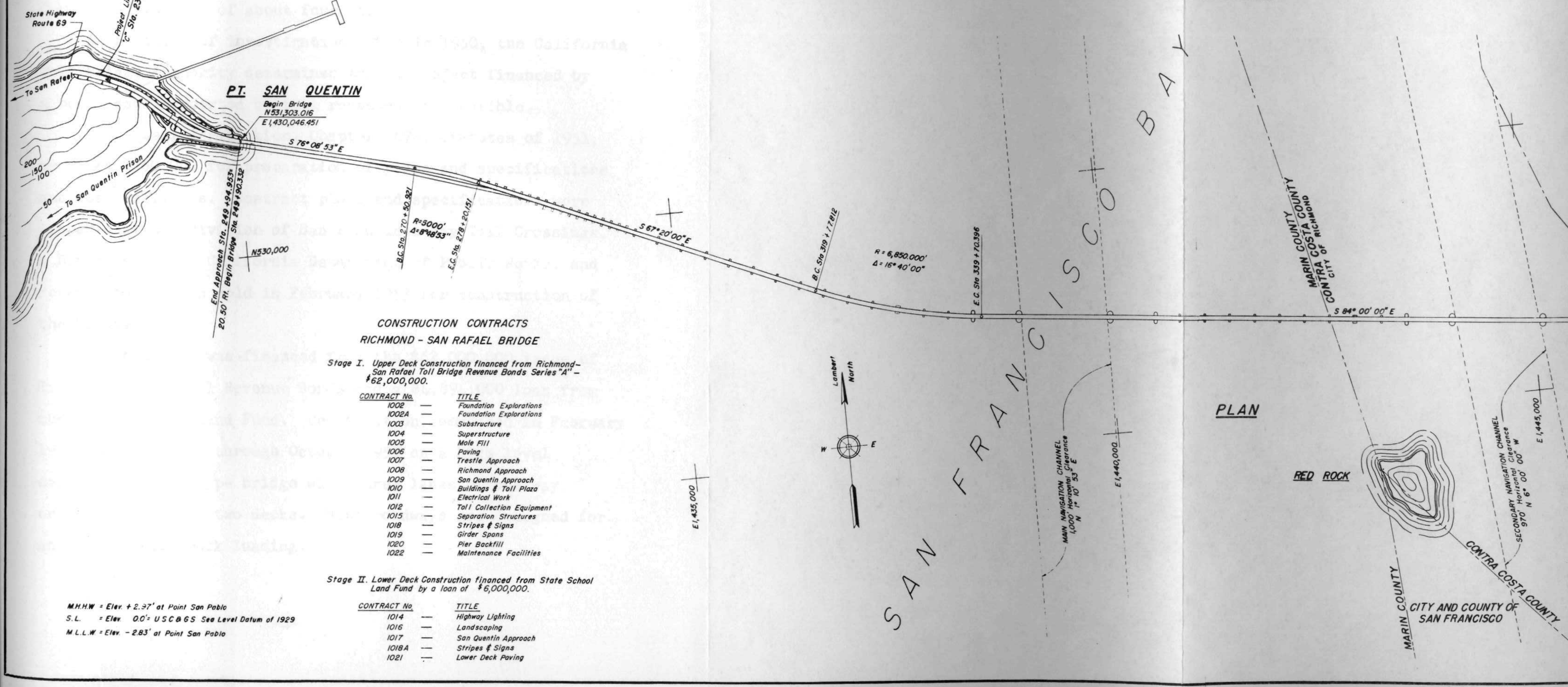
Due to the overstresses which would be caused in the main supporting members of the bridge, the extreme cost and doubtful practicability of remodeling and the contractual obligations to the outstanding bond holders, it is recommended that the Richmond-San Rafael Bridge not be used for rapid transit purposes.

FIG. I.


Total Length of Project = 29,140.960' = 5.52 Miles
Upper Deck = 21,345.098'
Total Length of Bridge = Lower Deck = 21,335.518'
Richmond Approach 5901.735'
1,550' V.C.
1,908.333' @ - 3.00%
1,400' V.C.
241.667' @ + 3.00%
1,550' V.C.
2,344.000' @ - 3.00%
1,459' V.C.
700.000' @ - 0.30%
500' V.C.
515.000' @ - 3.00%
070' V.C.
-3.00%
1,400' V.C.
+3.00%
1,070' V.C.
-3.00%
Elev. +69.494'
Elev. +43.694'
Sta. 463+34.604 End Bridge
End Approach Sta. 340+01.735
℄ Toll Plaza
Project Limits Sta. 281+00.00
187.97'
187.97'
S.L.
1,000'
480'
137.97'
S.L.
137.97'
1,000'
480'
480'
E E
F F
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 65 70 75 78
350
400
450
330 320 310 300 290
1,070.0'
537.5'
293.0'
6 @ 292.0' = 1,752.0'
290.5'
36.0'
290.5'
293.0'
537.5'
1,070.0'
537.5'
293.0'
7 @ 292.0' = 2,044.0'
293.0'
293.0'
292.0'
290.5'
17 @ 100.0' = 1700.0'
15.0'
Cantilever Span
289' Truss Spans
East Cantilever Span
289' Truss Spans
Plate Girder Spans
ELEVATION
ISCO BAY
MAIN NAVIGATION CHANNEL 1,000' Horizontal Clearance N 1° 10' 53" E
E 1,440,000
PLAN
RED ROCK
MARIN COUNTY
CONTRA COSTA COUNTY
CITY OF RICHMOND
S 84° 00' 00" E
MARIN COUNTY
CITY AND COUNTY OF SAN FRANCISCO
CONTRA COSTA COUNTY
SECONDARY NAVIGATION CHANNEL 970' Horizontal Clearance N 6° 00' 00" W
E 1,445,000
PIERHEAD LINE
CASTRO ROCKS
CASTRO PT.
Ferry Pier
E 1,450,000
50 100 150 200 250 300 350 400
B.C. Sta. 457+87.122
E.C. Sta. 461+36.188
R = 4000'
Δ = 5°00'00"
End Bridge
N 527,215.436
E 1,450,834.505
B.C. Sta. 450+79.545
E.C. Sta. 453+58.798
R = 4000'
Δ = 4°00'00"
S 89°00'00" E
BULKHEAD LINE
End Approach - App. Sta. 340+01.735 =
27.743' Rt. End Bridge - Br. Sta. 463+34.604
℄ Toll Plaza
RICHMOND
300 250 200 150 100 50
50 100 50 100 100 50 0
Project Limits
Sta. 281+00.00
Castro Street
State Highway Route 69
N. 525,882.971
E. 1,456,367.814
NOTE:
Lambert bearings are shown. Lambert bearing of True North at Red Rock is N. 1° 10' 53" E.



ELEVATION



PLAN

CONSTRUCTION CONTRACTS

RICHMOND - SAN RAFAEL BRIDGE

Stage I. Upper Deck Construction financed from Richmond-San Rafael Toll Bridge Revenue Bonds Series "A" - $62,000,000.

CONTRACT No.		TITLE
1002	—	Foundation Explorations
1002A	—	Foundation Explorations
1003	—	Substructure
1004	—	Superstructure
1005	—	Mole Fill
1006	—	Paving
1007	—	Trestle Approach
1008	—	Richmond Approach
1009	—	San Quentin Approach
1010	—	Buildings & Toll Plaza
1011	—	Electrical Work
1012	—	Toll Collection Equipment
1015	—	Separation Structures
1018	—	Stripes & Signs
1019	—	Girder Spans
1020	—	Pier Backfill
1022	—	Maintenance Facilities

Stage II. Lower Deck Construction financed from State School Land Fund by a loan of $6,000,000.

CONTRACT No.		TITLE
1014	—	Highway Lighting
1016	—	Landscaping
1017	—	San Quentin Approach
1018A	—	Stripes & Signs
1021	—	Lower Deck Paving

M.H.H.W = Elev. + 2.97' at Point San Pablo
S.L. = Elev. 0.0' = U S C & G S Sea Level Datum of 1929
M.L.L.W = Elev. - 2.83' at Point San Pablo

II INTRODUCTION

GENERAL

The Richmond-San Rafael Bridge crosses the northern arm of San Francisco Bay to provide Marin County with a direct connection to the East Bay. It crosses the Bay from Point San Quentin in Marin County to Castro Point in Contra Costa County, a distance of about four miles.

As a result of investigations made in 1950, the California Toll Bridge Authority determined that a project financed by a bond issue supported by toll revenues was feasible.

Subsequent legislation, Chapter 1473, Statutes of 1951, provided $750,000 for preparation of plans and specifications and cost estimates. Contract plans and specifications were prepared by the Division of San Francisco Bay Toll Crossings, a Division of the California Department of Public Works, and revenue bonds were sold in February 1953 for construction of the bridge.

Construction was financed from the $62,000,000 issue of Richmond-San Rafael Revenue Bonds and a $4,894,000 loan from the State School Land Fund. Construction commenced in February 1953 and continued through October 1957 on a high level cantilever truss type bridge with three lanes of one-way traffic on each of two decks. Both roadways are designed for an H-20-S16-44 truck loading.

PROJECT DESCRIPTION

The general plan and elevation of the bridge is shown in Figure 1. Commencing at Point San Quentin, the bridge consists of 2,800 feet of trestle which connects to 1,900 feet of 100-foot girder spans. The girders are connected to the cantilever structure over the main navigation channel by 4,100 feet of 289-foot truss spans. The span of this cantilever structure is 1,070 feet center to center of the piers with anchor arms of 537 feet, and provides 1,000 feet of horizontal clearance and 185 feet of vertical clearance for shipping. Between this structure and the cantilever over the secondary or easterly navigation channel are 3,000 feet of additional 289-foot truss spans. The secondary channel cantilever has spans as noted for the main channel but vertical clearance is limited to 135 feet. From this location to the vicinity of Castro Point, in Richmond, there are 3,500 feet of 287-foot simple truss spans and 1,700 feet of 100-foot plate girder spans terminating the overwater structure on earth fill.

The toll project also included connecting highway approaches between the bridgeheads and State Route 69, both in Marin and Contra Costa Counties, as well as administration and maintenance buildings, toll collection facilities located at the Richmond bridgehead.

TRAFFIC

An estimate of traffic was prepared prior to the sale of bonds in order to determine the size of bond issue that could be supported from the revenue generated.

The sources from which the bridge would derive its traffic are as follows:

1. The existing ferry traffic.
2. Diversions from parallel facilities.
3. New traffic generated as a result of the improved facility.
4. Future increases resulting from growth of the tributary area.

On the basis of these volumes the traffic consultants estimated that 3,939,000 vehicles would cross the bridge in 1958 - the first full year following completion; and estimated that the growth rate would approximate 200,000 vehicles per year. The actual volume in 1958 was 2,781,716 vehicles, in 1963 was 4,143,049, an average growth rate of 226,888 vehicles per year. Although the initial volume was less than estimated, the growth rate has been greater than predicted, and toll revenues have been sufficient to meet all current obligations.

RAPID TRANSIT TO MARIN COUNTY

Under the provisions of Chapter 1760 of the Statutes of 1951, the San Francisco Bay Area Rapid Transit Commission was assigned the responsibility of bringing about the development of a coordinated rapid transit plan for the San Francisco Bay Area. The master plan contemplated a route serving Marin County via the existing Golden Gate Bridge and BARTD consultant, C. H. Gronquist, found such to be possible subject to modification of the bridge. However, the Golden Gate Bridge and Highway District, which is responsible for the operation, employed consultant Clifford E. Payne, who found that installation of rapid transit trains on the bridge would cause deflection and stresses that would be beyond safe limits. A third study by an Engineering Review Board confirmed the latter findings. As a result of this obstacle, Marin County withdrew from the Bay Area Rapid Transit District.

Further investigations of a rapid transit link between San Francisco and Marin Counties were initiated by the Division of Bay Toll Crossings as part of the San Francisco-Marin Crossing Study authorized by Chapter 2142 of the Statutes of 1961. As this study was halted prior to its completion there were no recommendations made with regard to the rapid transit facilities. It is anticipated, however, that when these additional studies are made the feasibility of providing rapid transit on the crossing will be included in the investigations.

Recently provision was made by the legislature for inaugurating a modern mass transit system for Marin County.

During the 1964 Session a bill was passed authorizing the formation of the Marin County Transit District. Plans by this District for the implementation of a mass transit system are presently in a formative stage.

AUTHORIZATION

Senate Bill No. 79, Chapter 118 of the First Extraordinary Session, appropriated the sum of $12,000 from the Revenue Fund of the San Francisco-Oakland Bay Bridge for the purpose of investigating the possibility of using the Richmond-San Rafael Bridge for rapid transit use taking into consideration the weight of the rapid transit vehicles and the ability of the bridge to withstand the strains incident to their movement over the bridge and submit a report to the legislature not later than the fifth day of the 1965 Regular Session of the Legislature. A copy of this bill is included in this report as Appendix A.

PREVIOUS STUDIES

Parsons, Brinckerhoff, Hall and McDonald, consultants to the San Francisco Bay Area Rapid Transit Commission, studied the possibility of using the Richmond-San Rafael Bridge for rapid transit service between Contra Costa and Marin Counties. Their conclusion, as reported in Regional Rapid Transit, 1953-1955, was that, for the conditions studied, the bridge was inadequate to withstand the proposed rapid transit loads. An excerpt from this report is included as Appendix B.

Since the inclusion of this route in the overall system was considered to be necessary only in the latter stages of its development this investigation was limited in scope.

A more detailed analysis of the possible use of the Richmond-San Rafael Bridge for rapid transit purposes is contained in the following chapters.

III PRELIMINARY STUDIES

CONSULTATIONS

On September 21, and September 23, 1964, representatives of the Division of Bay Toll Crossings met with the representatives of the Bay Area Rapid Transit District (BARTD) to discuss the possible approach alignments, the possible arrangements of tracks on the bridge, the methods of determining passenger diversions, and the design criteria presently being used by the District for its alignment geometry and structural analysis.

The following information was received at that time and has been used where applicable in the preparation of this report:

1. "Civil and Structural Design Criteria", Engineering Dept., Parsons, Brinckerhoff-Tudor-Bechtel.
2. "Special Study, Richmond-San Rafael Bridge" for Bay Area Rapid Transit Commission Report, 1953-1955.
3. "Traffic Distribution Forecasts - Highway and Transit", Henry D. Quimby - Traffic Engineering, Feb. 1961.

APPROACHES

As part of this study, approach routes to the bridge from the Richmond Station of the BARTD system and a possible San Rafael Station were briefly investigated. Discussions were held with BARTD representatives, but no detailed location studies were made. There are many problems which would have to be resolved by further investigation but it is considered that such connections are possible.

TRACK ARRANGEMENT

Various methods of carrying the rapid transit tracks on the bridge structure were considered. Six possible schemes are shown in Figure 2, Track Arrangements, and the advantages and disadvantages of each one are discussed in the following paragraphs.

Scheme 1 provides for the smallest increase in dead load on the structure and retains the one-way traffic on adjacent lanes for each deck. It reduces the vehicular carrying capacity by both the lane elimination and a reduction of remaining lane width from 12 feet to 11 feet. The revised capacity is estimated at 64 percent of the original capacity.

In Scheme 2, the existing traffic service remains unchanged as the tracks are supported on cantilever arms on the outside of the trusses. It results in a considerable increase in the dead loading due to the additional structure. Further, the rapid transit live load is in addition to the existing six lanes of highway live load.

Scheme 3 is the most efficient one from a structural standpoint due to minimum amount of added structure and the symmetrical placement of rapid transit loading. However, it could not be considered as an acceptable arrangement from a traffic standpoint, since the two lanes of highway traffic on each deck would be separated by rapid transit tracks.

This condition does not allow for any passage of traffic around slow moving or disabled vehicles.

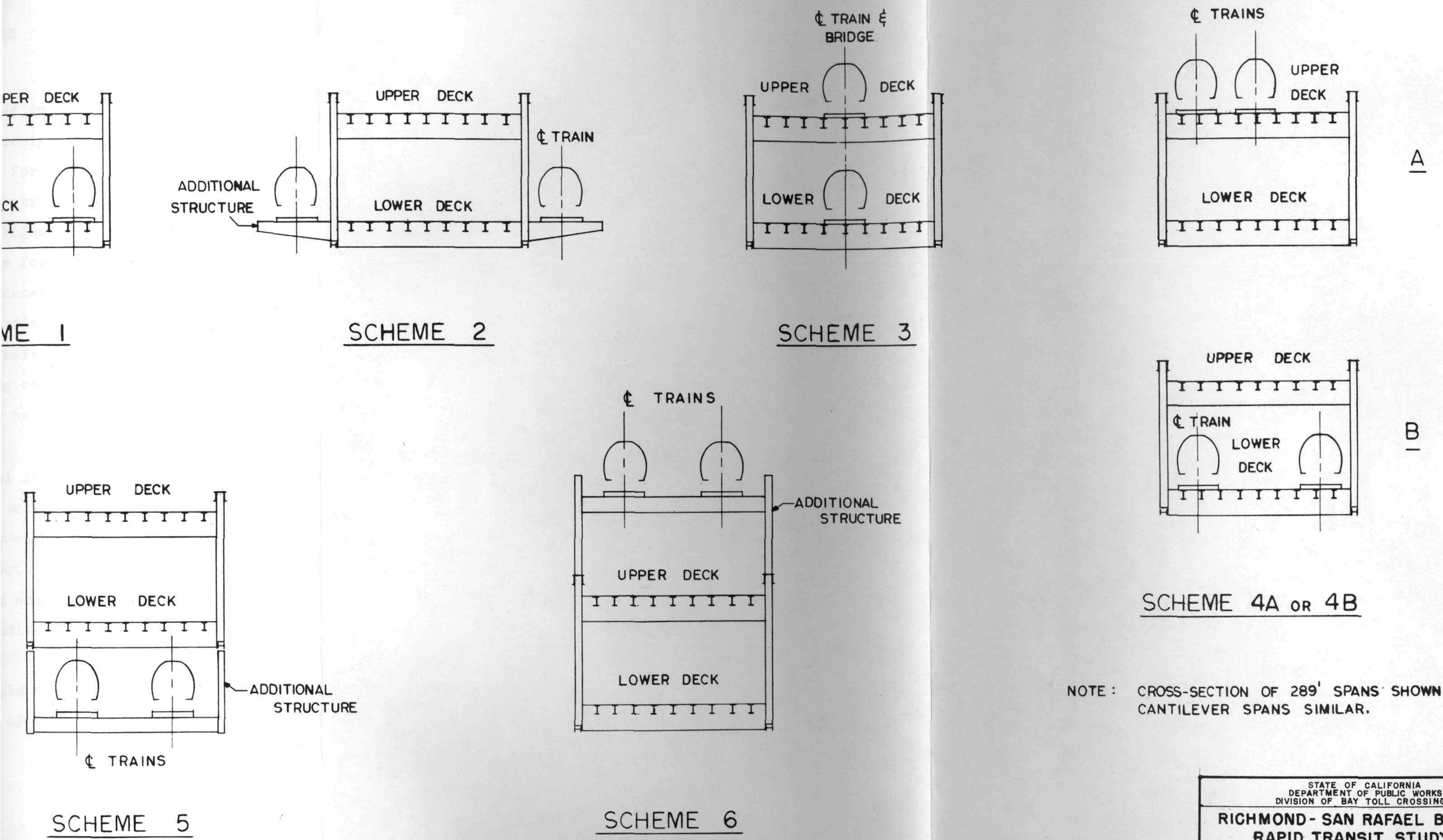
In Scheme 4 the two rapid transit tracks and the attendant structural modification would be confined to a single deck of the bridge. Two-way traffic would result on the other deck thus eliminating the safety feature of the one-way operation. Also extensive modifications of the approaches would be required at each end of the bridge. As in the previous arrangement, the single lane of traffic on the deck with the rapid transit tracks would not provide adequate traffic service.

As in Scheme 2, Scheme 5 results in no revisions to the existing traffic service. The tracks are suspended on additional structural elements below the existing lower deck with the resultant dead and live load increases of Scheme 2. This suspended structure would infringe upon the navigation clearance requirements established by The Department of Army for the original construction of the bridge. Therefore, this arrangement is also considered unacceptable.

Scheme 6, with the tracks supported over the upper deck of the bridge, has the disadvantage of the large increase in dead and live loads. In addition, major structural revisions would be required due to the interference with the portal bracing of the cantilever spans.

For the reasons discussed above, it was determined that only Schemes 1 and 2 should be investigated with regard to their structural adequacy because the other arrangements were either unacceptable for traffic service or navigation, or were similar to Scheme 2 with regard to additional loadings.

FIG. 2.



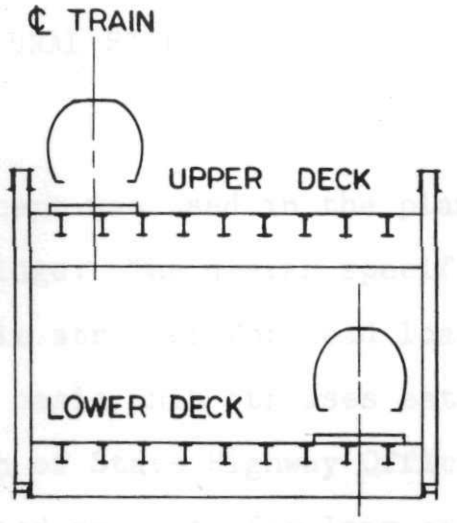
NOTE: CROSS-SECTION OF 289' SPANS SHOWN - CANTILEVER SPANS SIMILAR.

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF BAY TOLL CROSSINGS

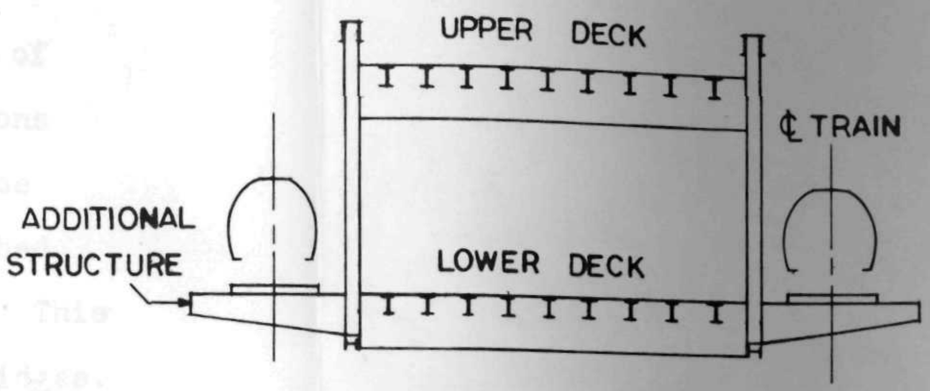
RICHMOND-SAN RAFAEL BRIDGE
RAPID TRANSIT STUDY

TRACK ARRANGMENTS

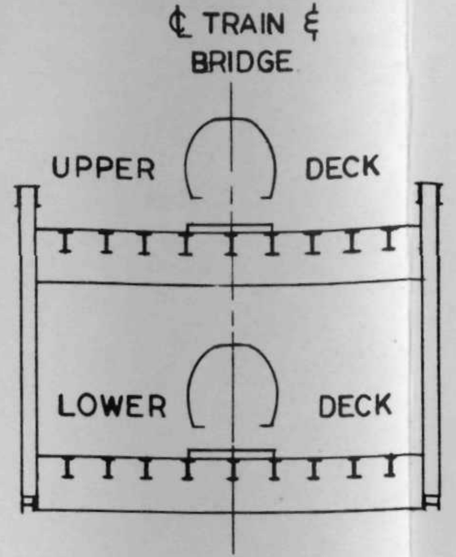
SCALE 1"=20'	BRIDGE NO. 28-100	SHT. NO.	DRWG. NOM-1030-5



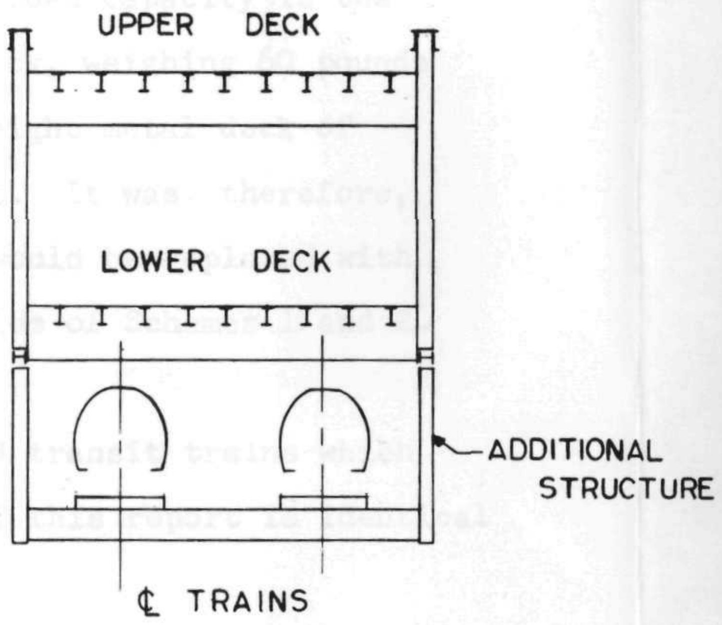
SCHEME 1



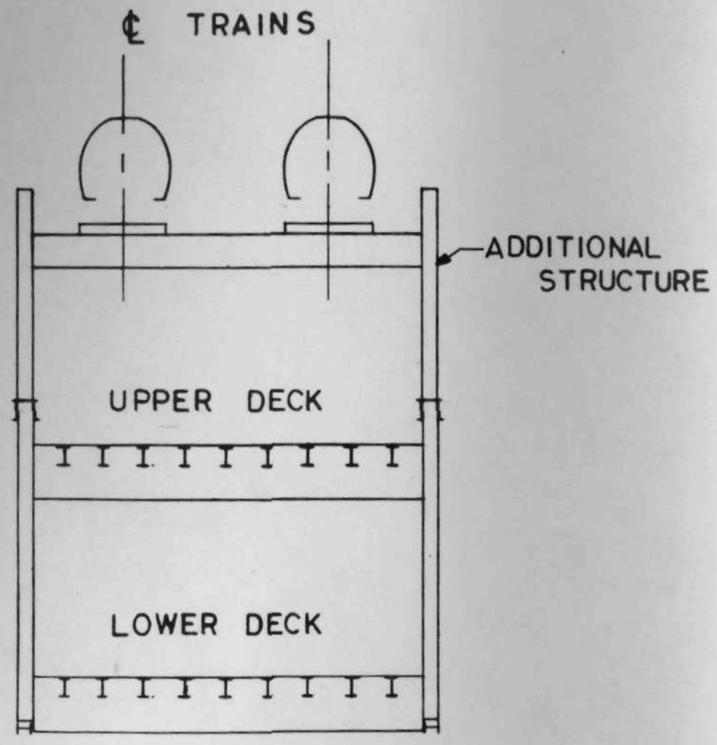
SCHEME 2



SCHEME 3



SCHEME 5



SCHEME 6

NOTE

IV STRUCTURAL STUDIES

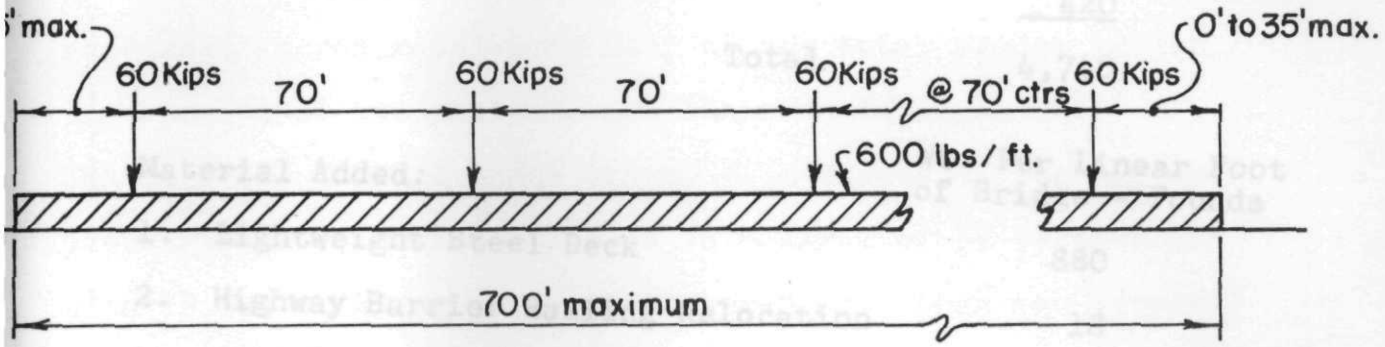
GENERAL CONSIDERATIONS

A balanced design concept was used in the planning of the Richmond-San Rafael Bridge. The design specifications permitted the allowable unit stresses for dead load to be one third greater than the basic unit stresses established by the American Association of State Highway Officials. This is an economical and accepted practice for long-span bridges. However, this procedure results in reduced reserve capacity for future additions. For a corresponding one third increase in the live load a minimum factor of safety of 1.38 results for the combined loading. Any loading conditions resulting in a decrease in the factor of safety below this limit are unacceptable.

One means of providing additional load capacity is the replacement of the existing concrete deck, weighing 60 pounds per square foot, with a special lightweight metal deck of approximately 20 pounds per square foot. It was, therefore, assumed that the entire existing deck would be replaced with a lightweight deck in the further studies of Schemes 1 and 2.

RAPID TRANSIT LOADING

The design live load for the rapid transit trains which was used for the stress calculations of this report is identical with that used by the BARTD consulting engineers, Parsons, Brinckerhoff-Tudor-Bechtel. A pictorial representation of this loading is shown below.



RAPID TRANSIT LOADING

RAPID TRANSIT STRESSES

The procedure used in determining the stresses in the individual members of the bridge with the proposed addition of rapid transit facilities was as follows:

a. The net decrease in dead load due to the replacement of the concrete roadway with a lightweight deck and the addition of rapid transit facilities was computed. The tabulation below shows the results of a typical computation for the 289-foot truss spans using Scheme 1 loading, as depicted in Figure 3.

Material Removed:	Wt. Per Linear Foot of Bridge - Pounds
1. Concrete Slab	4,320
2. Stringers	420
Total	4,740

Material Added:	Wt. Per Linear Foot of Bridge - Pounds
1. Lightweight Steel Deck	880
2. Highway Barrier Railing Relocation	18
3. Skid Girders	195
4. Stringers	472
5. Rapid Transit Rails, Ties & Walkways	868
Total	2,433

As indicated above the net decrease in dead load is equal to 2,307 pounds per foot of bridge.

b. The rapid transit live load and impact stresses, using the loading described previously, were computed.

c. The reduction of the highway live load stresses due to the elimination of two lanes of traffic was computed for Scheme 1.

d. Using the data developed above, new stresses were computed for the main supporting structural members. These new stresses were then compared with the design allowable stresses and AASHO allowable stresses. In addition, the factor of safety for each member also was computed.

289-Foot Truss Spans - See Figures 3 and 4

The 289-foot truss spans were investigated first since the stress analysis is relatively simple and these spans represent approximately one half of the total bridge length. The results of the analysis are shown on Table 1 for Scheme 1 and Table 2 for Scheme 2. Because of the extreme overstresses found for Scheme 2 (a maximum of 59 percent and with 19 out of 27 members overstressed more than ten percent) it was concluded that Scheme 2 need be considered no further. Although Scheme 1 contained some overstress, this scheme was investigated throughout the remaining length of the structure.

Main Channel Spans - See Figure 3

The results of this analysis are tabulated on Tables 3 through 5 . It can be seen that many of the members are highly overstressed and approximately 20 percent of them have a factor of safety below the minimum allowable of 1.38.

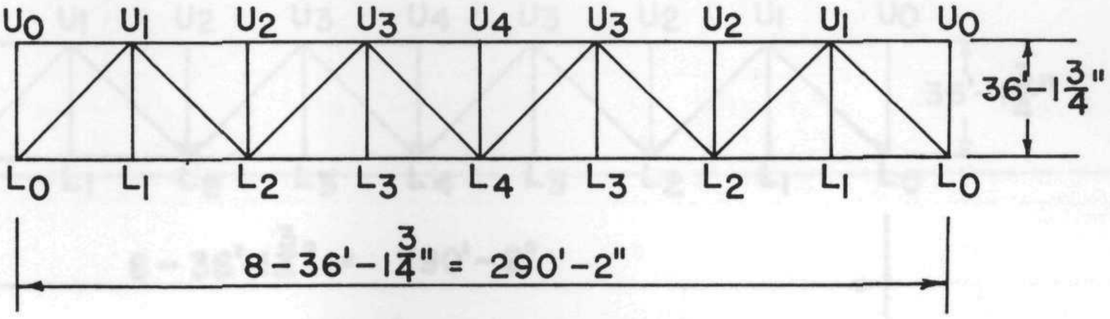
Plate Girder Spans - See Figure 5

Because of the weight saving obtained by replacement of 10-1/2 inch thick concrete roadway slab used on these spans it was found that the floor beams and plate girders would not be overstressed with the addition of rapid transit. The allowable deflection, however, would be exceeded by 35 percent.

Trestle - See Figure 6

No reduction in dead load can be obtained through replacement of the concrete deck in this area because it would destroy the integrity of the deck supporting system. Consequently it would be necessary to construct additional trestle structure to accommodate rapid transit.

TABLE 1


U0 U1 U2 U3 U4 U3 U2 U1 U0
L0 L1 L2 L3 L4 L3 L2 L1 L0
36'-1$\frac{3}{4}$"
8-36'-1$\frac{3}{4}$" = 290'-2"

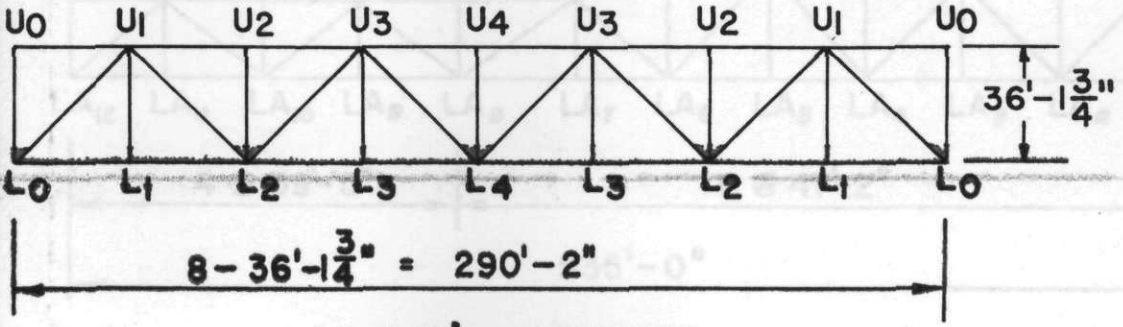
289' SPANS

SCHEME 1

Member	Stress (KS1)	OVERSTRESS With Respect To: Design Spec. Allowable Stress %	AASHO Spec. Allowable Stress %	Factor Of Safety
L_0L_2	34.1	3	14	1.32*
L_2L_4	33.5	3	19	1.56
U_1U_3	22.6	5	20	1.56
U_3U_4	22.1	4	18	1.59
L_0U_1	20.0	4	19	1.56
U_1L_2	20.6	8	23	1.52
L_2U_3	20.8	18	32	1.43
U_3L_4	25.4	23	41	1.30*
U_1L_1	33.2	6	6	1.35*
U_3L_3	33.2	6	6	1.35*
U_2L_3	32.1	6	10	1.35*
U_4L_4	32.1	6	10	1.35*
U_0L_0	17.2	0	0	2.50
U_0U_1	—	—	—	—

*Less than the minimum allowable factor of safety of 1.38

TABLE 2



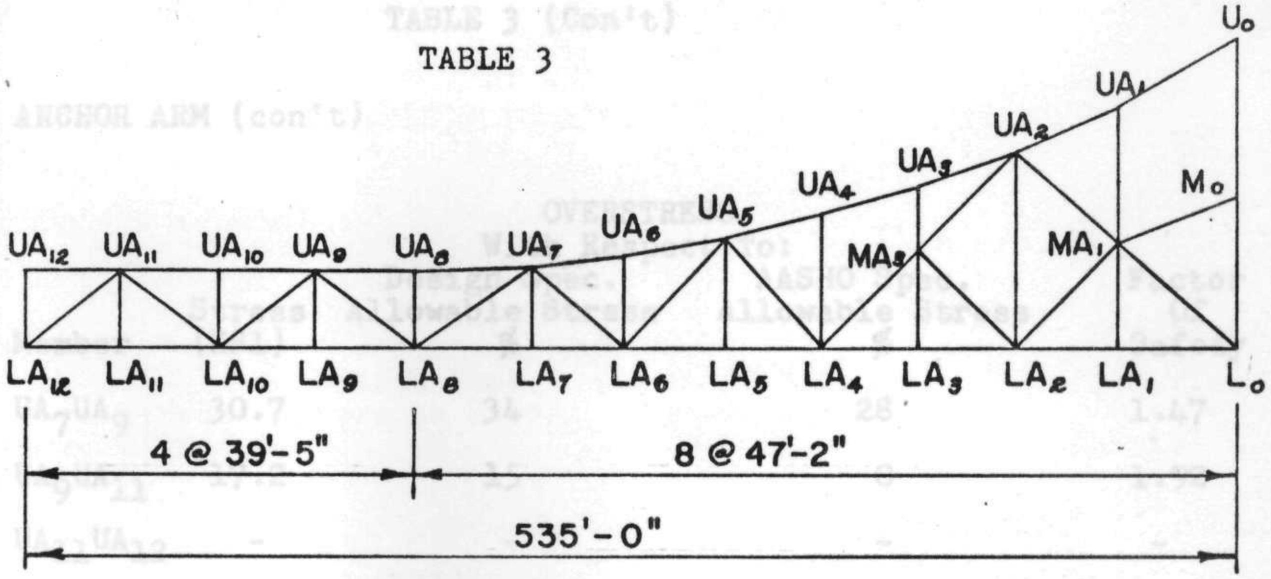
289' SPANS

SCHEME 2

Member	Stress (KSI)	OVERSTRESS With Respect To: Design Spec. Allowable Stress %	OVERSTRESS With Respect To: AASHO Spec. Allowable Stress %	Factor Of Safety
L_0L_2	38.6	16	29	1.16*
L_2L_4	33.1	20	38	1.35*
U_1U_3	26.3	22	40	1.33*
U_3U_4	25.9	21	38	1.35*
L_0U_1	23.4	21	39	1.33*
U_1L_2	34.4	27	43	1.32*
L_2U_3	24.4	39	54	1.20*
U_3L_4	31.9	59	69	1.03*
U_1L_1	34.7	10	11	1.30*
U_3L_3	34.7	10	11	1.30*
U_2L_3	33.5	14	15	1.30*
U_4L_4	33.5	14	15	1.30*
U_0L_0	17.9	0	0	2.44
U_0U_1	—	—	—	—

*Less than allowable factor of safety of 1.38

TABLE 3



ANCHOR ARM

Member	Stress (KSI)	OVERSTRESS With Respect To: Design Spec. Allowable Stress %	AASHO Spec. Allowable Stress %	Factor Of Safety
L_0LA_2	31.6	3	15	1.59
LA_2LA_4	31.4	1	14	1.61
LA_4LA_6	28.5	13	22	1.23*
LA_6LA_8	28.9	19	23	1.21*
LA_8LA_{10}	31.0	26	30	1.16*
$LA_{10}LA_{12}$	21.2	5	0	1.56
U_0UA_1	31.8	5	25	1.56
UA_1UA_2	31.9	5	25	1.56
UA_2UA_3	33.8	16	32	1.64
UA_3UA_4	34.2	17	34	1.61
UA_4UA_5	33.7	16	32	1.61
UA_5UA_7	33.7	25	40	1.33*

*Less than the allowable factor of safety of 1.38

TABLE 3 (Con't)

ANCHOR ARM (con't)

		OVERSTRESS With Respect To:		
Member	Stress (KS1)	Design Spec. Allowable Stress %	AASHO Spec. Allowable Stress %	Factor Of Safety
UA_7UA_9	30.7	34	28	1.47
UA_9UA_{11}	17.2	15	0	1.92
$UA_{11}UA_{12}$	-	-	-	-
L_0MA_1	29.7	6	14	1.52
MA_1UA_2	22.2	9	26	1.49
UA_2MA_3	29.8	7	24	1.52
MA_3LA_4	29.4	5	22	1.54
LA_4UA_5	19.7	1	19	1.54
UA_5LA_6	30.2	7	26	1.49
LA_6UA_7	20.4	7	24	1.49
UA_7LA_8	30.0	8	25	1.49
LA_8UA_9	21.8	13	28	1.47
UA_9LA_{10}	30.8	23	28	1.47
$LA_{10}UA_{11}$	24.4	40	42	1.32*
$UA_{11}LA_{12}$	24.7	40	37	1.37*
MA_1LA_2	10.6	0	0	2.00
MA_3LA_2	11.4	0	0	1.85
MA LA	33.5	1	12	1.35*

*Less than the minimum allowable factor of safety of 1.38

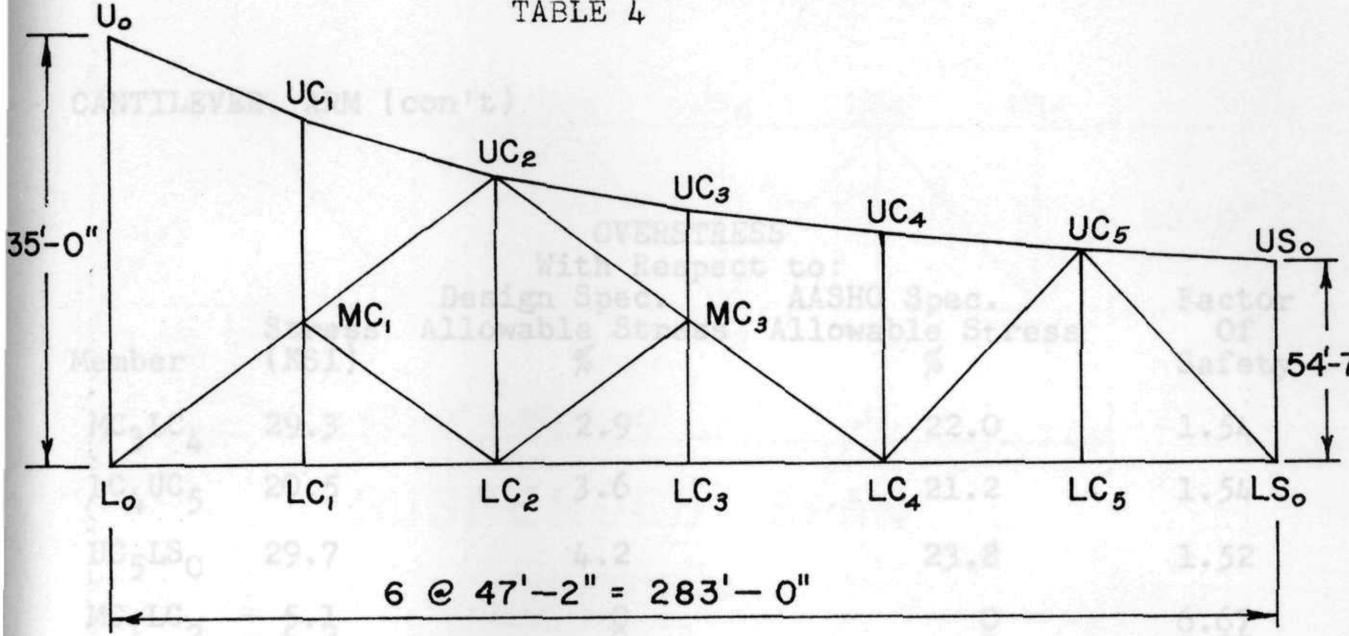
TABLE 3 (Con't)

ANCHOR ARM (con't)

		OVERSTRESS With Respect To:		
Member	Stress (KSI)	Design Spec. Allowable Stress %	AASHO Spec. Allowable Stress %	Factor Of Safety
MA_3LA_3	33.2	3.9	10.5	1.35*
UA_5LA_5	33.2	3.7	10.5	1.35*
UA_7LA_7	32.6	2.0	8.6	1.37*
UA_9LA_9	28.0	0	0	1.61
$UA_{11}LA_{11}$	28.0	0	0	1.61
UA_2LA_2	23.1	0	10.0	1.43
UA_1MA_1	8.6	0	0	3.85
UA_3MA_3	7.1	0	0	4.76
UA_4LA_4	25.2	0	0	1.79
UA_6LA_6	26.3	3.1	2.6	1.69
UA_8LA_8	26.1	2.3	2.0	1.72
$UA_{10}LA_{10}$	25.6	0.6	0	1.92
$UA_{12}LA_{12}$	16.6	0	0	2.70
M_0MA_1	—	—	—	—
U_0M_0	23.1	4.0	24.1	1.52
M_0L_0	23.4	0.4	25.1	1.49

*Less than the allowable factor of safety of 1.38

TABLE 4



CANTILEVER ARM

Member	Stress (KSl)	OVERSTRESS With Respect to: Design Spec. Allowable Stress %	AASHO Spec. Allowable Stress %	Factor Of Safety
L_0LC_2	30.3	1.2	12.0	1.61
LC_2LC_4	30.5	0	10.4	1.61
LC_4LS_0	19.1	0	0	2.32
U_0UC_1	31.6	3.9	24.0	1.59
UC_1UC_2	31.4	3.4	23.0	1.59
UC_2UC_3	24.3	0	0	2.04
UC_3UC_4	24.4	0	0	2.04
UC_4UC_5	24.6	0	0	2.04
UC_5US_0	0	Erection Stress Only		
L_0MC_1	29.5	1.6	11.3	1.69
MC_1UC_2	22.4	4.6	25.2	1.49
UC_2MC_3	29.4	2.9	22.5	1.54

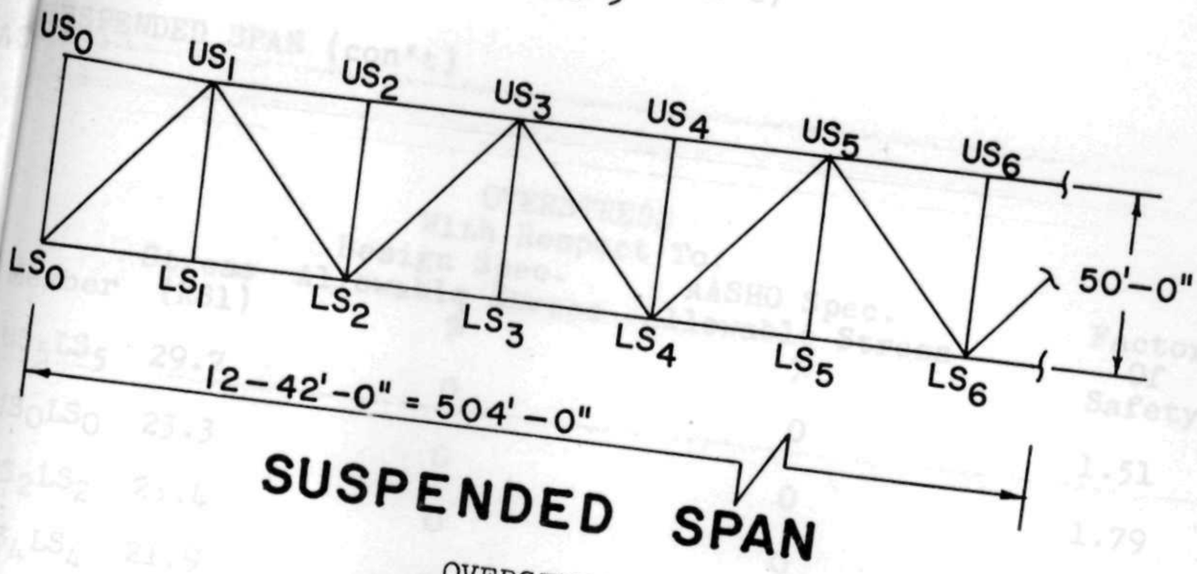
TABLE 4 (Con't)

CANTILEVER ARM (con't)

		OVERSTRESS With Respect to:		
Member	Stress (KSI)	Design Spec. Allowable Stress %	AASHO Spec. Allowable Stress %	Factor Of Safety
MC_3LC_4	29.3	2.9	22.0	1.54
LC_4UC_5	20.5	3.6	21.2	1.54
UC_5LS_0	29.7	4.2	23.8	1.52
MC_1LC_2	+ 5.1 - 4.2	0 0	0 0	6.67 5.27
MC_3LC_2	10.2	0	0	2.13
MC_1LC_1	33.9	5.5	12.8	1.33*
MC_3LC_3	22.9	2.9	0	1.37*
UC_5LC_5	32.1	0.5	7.0	1.41
UC_1MC_1	18.8	0	4.4	1.76
UC_2LC_2	19.5	0	0	1.69
UC_3MC_3	9.1	0	0	3.57
UC_4LC_4	24.0	0	0	2.04

*Less than the allowable factor of safety of 1.38

TABLE 5



Member	Stress (KS1)	OVERSTRESS With Respect To: Design Spec. Allowable Stress %	AASHO Spec. Allowable Stress %	Factor Of Safety
LS_0LS_2	32.3	0	8	1.39
LS_2LS_4	33.0	0	10	1.37*
LS_4LS_6	40.0	0	7	1.37*
US_1US_3	22.6	0	18	1.59
US_3US_5	23.1	3	21	1.54
US_5US_5	23.2	4	22	1.54
LS_0US_1	21.0	0	15	1.61
US_1LS_2	28.6	1	19	1.56
US_2US_3	21.3	4	23	1.51
US_3LS_4	29.8	7	24	1.51
LS_4US_5	19.3	6	21	1.56
US_5LS_6	22.5	11	25	1.47
US_1LS_1	29.4	0	0	1.54
US_3LS_3	34.5	0	15	1.30*

*Less than allowable factor of safety of 1.38

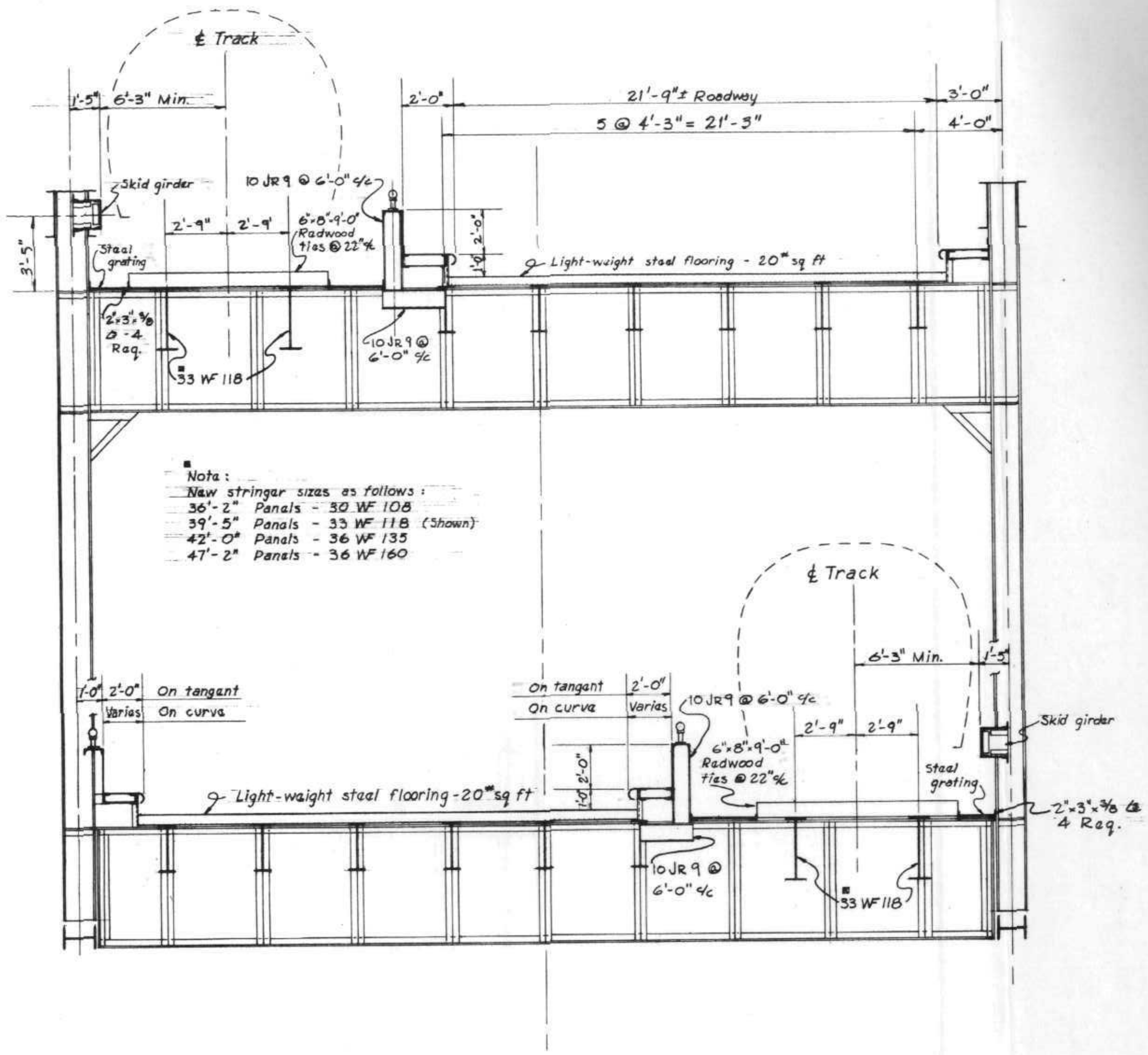
TABLE 5 (Con't)

SUSPENDED SPAN (con't)

		OVERSTRESS With Respect To:		
Member	Stress (KSI)	Design Spec. Allowable Stress %	AASHO Spec. Allowable Stress %	Factor Of Safety
US_5LS_5	29.7	0	0	1.51
US_0LS_0	23.3	0	0	1.79
US_2LS_2	23.4	0	0	1.72
US_4LS_4	21.9	0	0	1.85
US_6LS_6	21.7	0	0	1.85

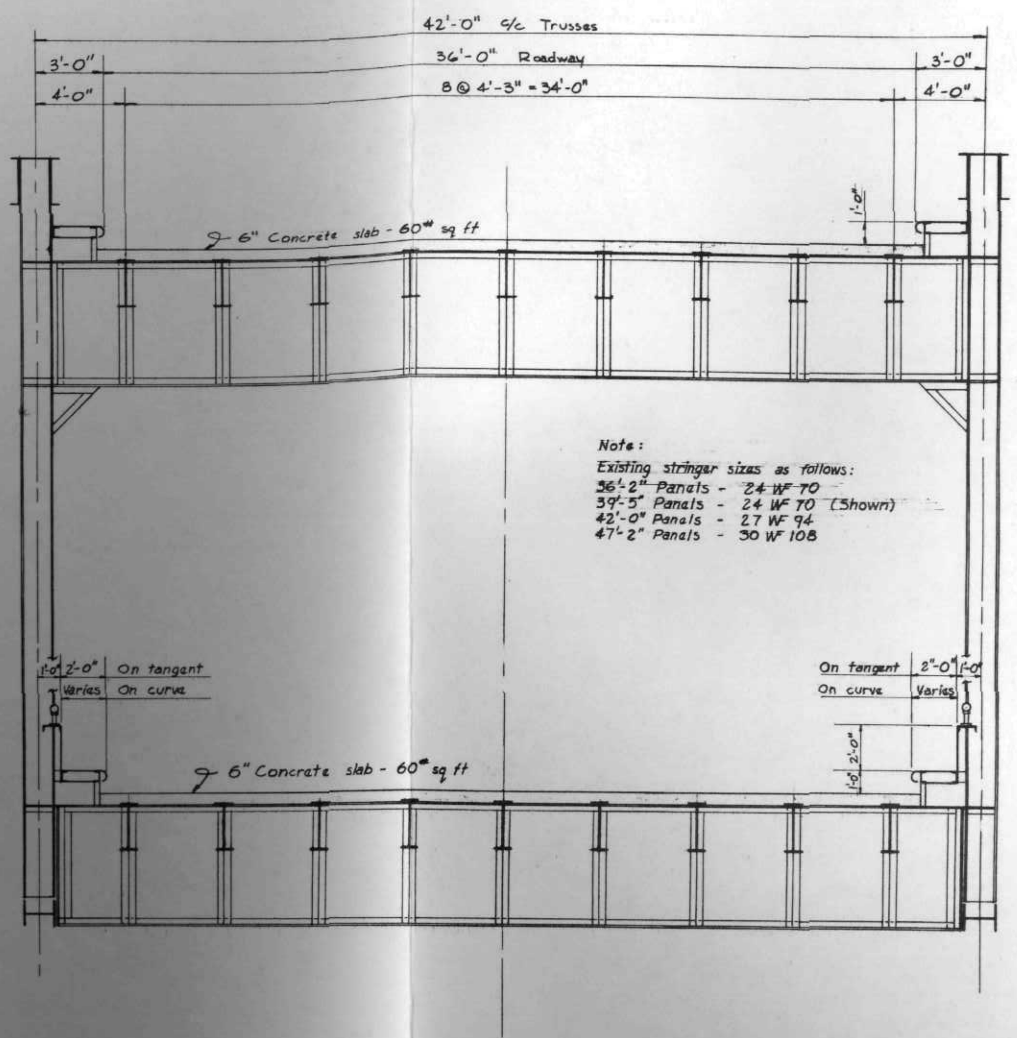
*Less than allowable factor of safety of 1.38

FIG. 3



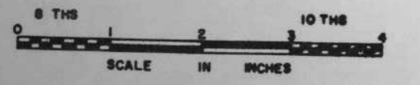
■ Note:
New stringer sizes as follows:
36'-2" Panels - 30 WF 108
39'-5" Panels - 33 WF 118 (Shown)
42'-0" Panels - 36 WF 135
47'-2" Panels - 36 WF 160

RICHMOND-SAN RAFAEL BRIDGE
SUPERSTRUCTURE
TYPICAL CROSS-SECTION (REVISED)
289' SPANS SHOWN



Note:
Existing stringer sizes as follows:
36'-2" Panels - 24 WF 70
39'-5" Panels - 24 WF 70 (Shown)
42'-0" Panels - 27 WF 94
47'-2" Panels - 30 WF 108

RICHMOND-SAN RAFAEL BRIDGE
SUPERSTRUCTURE
TYPICAL CROSS-SECTION (EXISTING)
289' SPANS SHOWN



SCHEME I

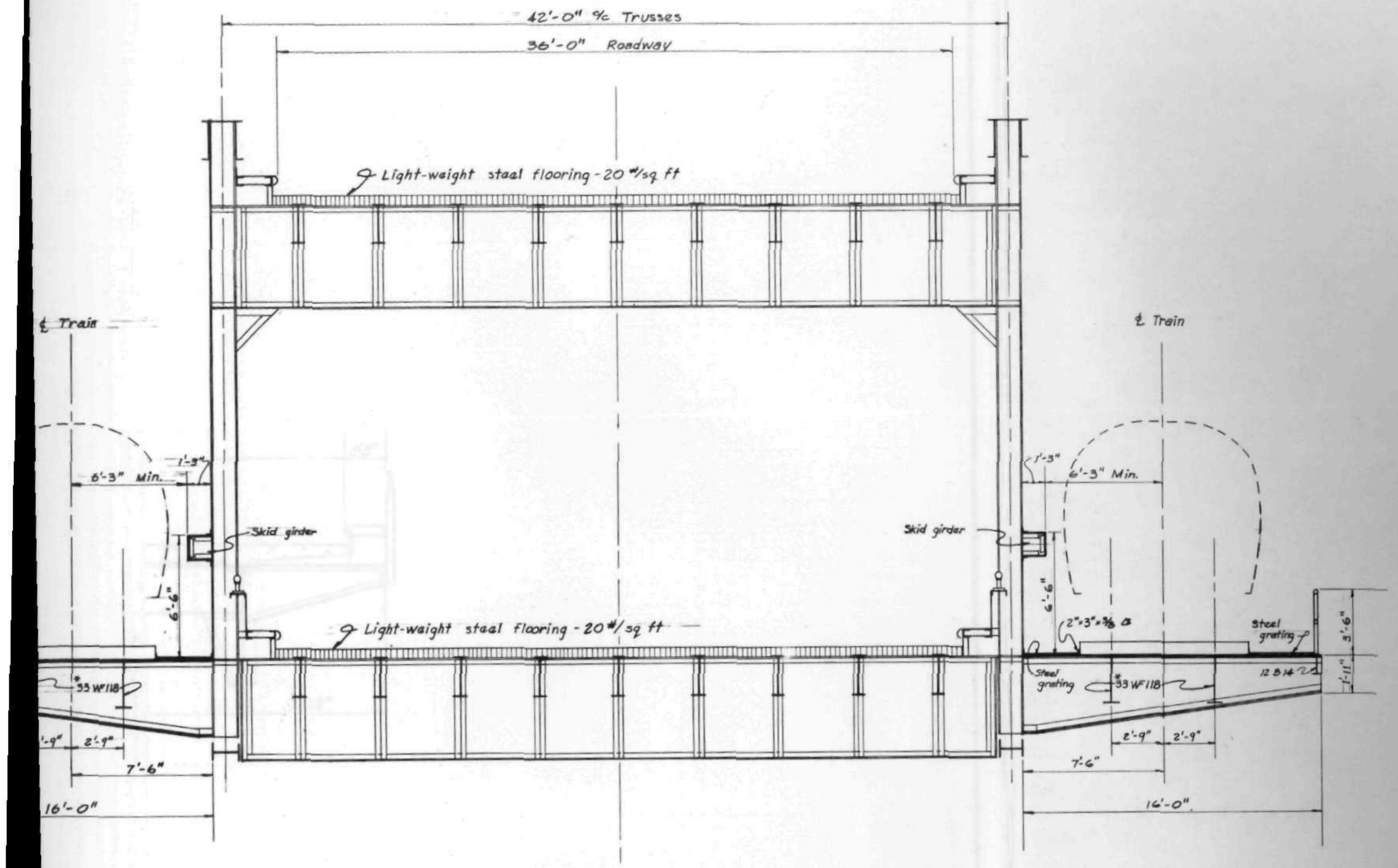
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF BAY TOLL CROSSINGS

RICHMOND - SAN RAFAEL BRIDGE
RAPID TRANSIT STUDY

TYPICAL CROSS-SECTION - TRUSS SPANS

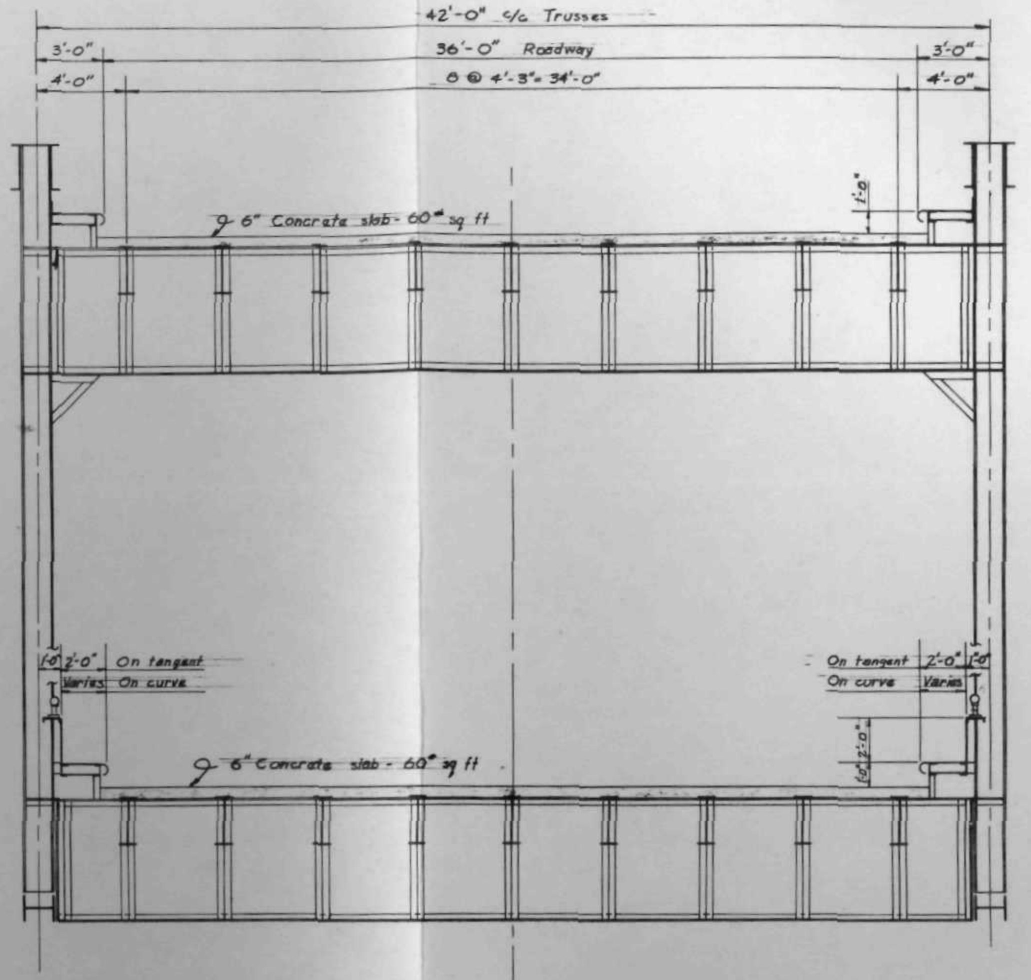
SCALE 1/4" = 1'-0"	BRIDGE 28-100	SHEET No.	DRAWING M-1030-2

FIG. 4



llows :
WF 108
WF 118 (shown)
WF 135
WF 160

RICHMOND - SAN RAFAEL BRIDGE
SUPERSTRUCTURE
TYPICAL CROSS-SECTION (REVISED)
289' SPANS SHOWN



RICHMOND - SAN RAFAEL BRIDGE
SUPERSTRUCTURE
TYPICAL CROSS-SECTION (EXISTING)
289' SPANS SHOWN

8 THS 10 THS
0 1 2 3 4
SCALE IN INCHES

SCHEME II

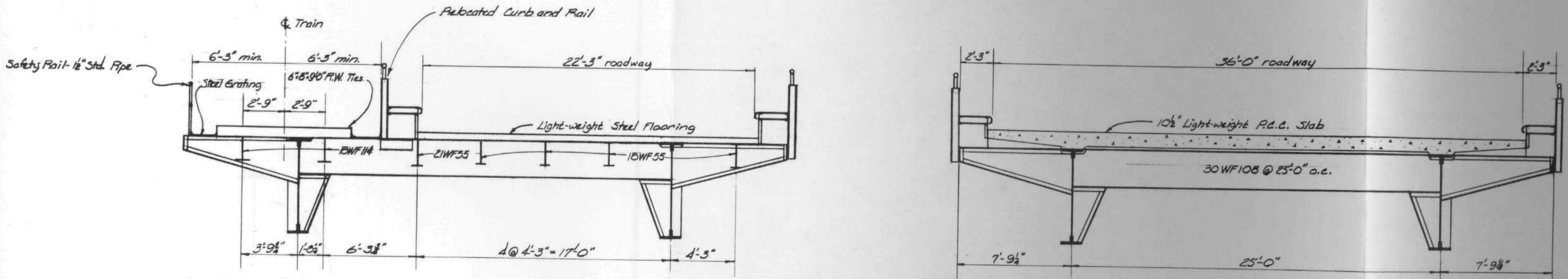
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF BAY TOLL CROSSINGS

RICHMOND - SAN RAFAEL BRIDGE
RAPID TRANSIT STUDY

TYPICAL CROSS - SECTION - TRUSS SPANS

SCALE 1/4" = 1'-0"	BRIDGE 28-100	SHEET NO.	DRAWING M-1030-3

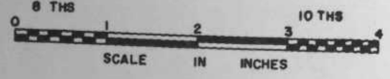
FIG. 5.



(MODIFIED FOR RAPID TRANSIT)

(EXISTING)

TYPICAL CROSS SECTION – 100'-0" SPANS



SCHEME I

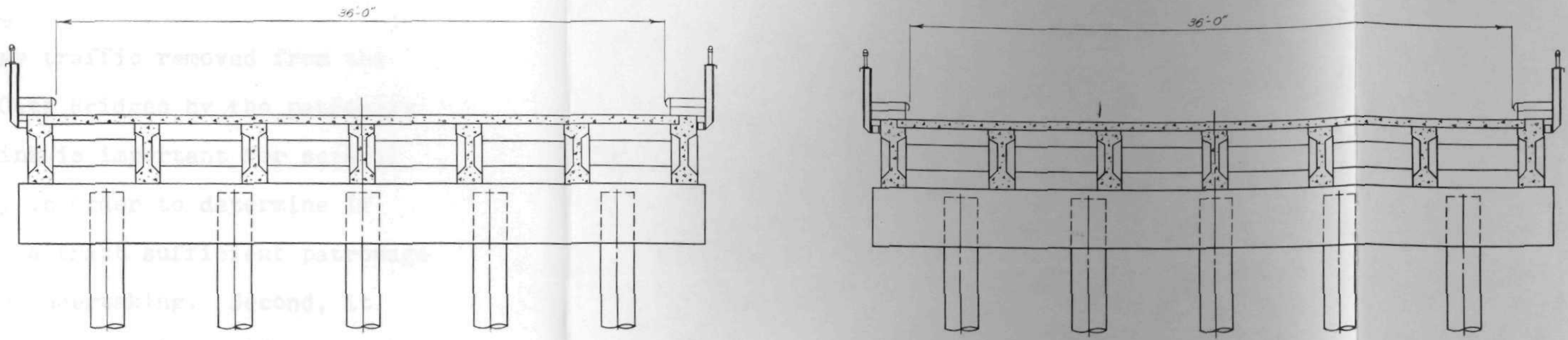
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF BAY TOLL CROSSINGS

RICHMOND - SAN RAFAEL BRIDGE
RAPID TRANSIT STUDY

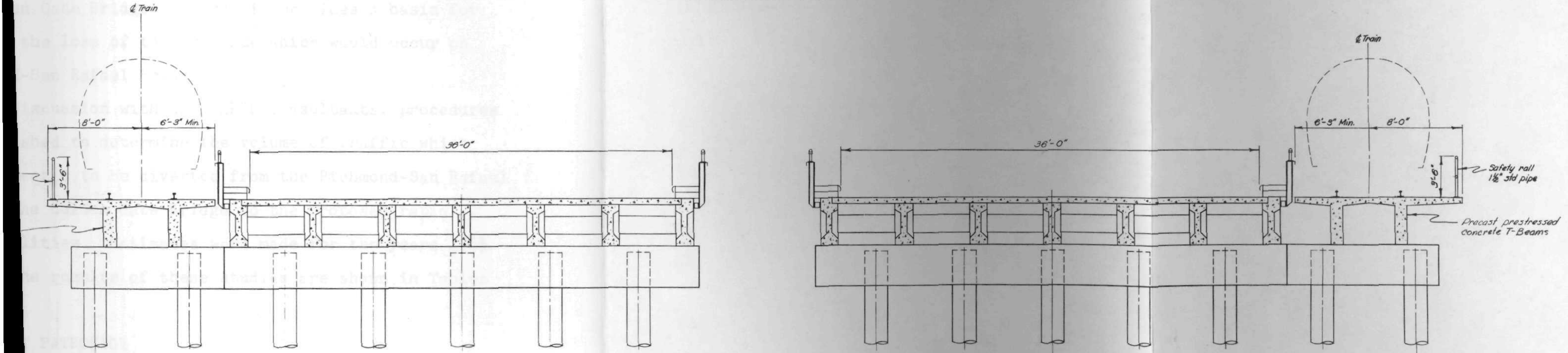
TYPICAL CROSS-SECTION-GIRDER SPANS

SCALE 1/4" = 1'-0"	BRIDGE 28-100	SHEET NO.	DRAWING M-1030-4

FIG. 6.



EXISTING TRESTLE



TRESTLE MODIFIED FOR RAPID TRANSIT

8 THS 0 1 2 3 10 THS 4
SCALE IN INCHES

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF BAY TOLL CROSSINGS

RICHMOND-SAN RAFEAL BRIDGE
BAY AREA RAPID TRANSIT STUDY

TYPICAL CROSS SECTION-TRESTLE SPANS

SCALE : ¼"= 1'-0"	BRIDGE 28-100	SHEET No.	DRAWING M-1030-6

REVISION	A	B	C	D	E	F	TRACED

V TRAFFIC AND REVENUE

DIVERSIONS TO RAPID TRANSIT

An estimate of the vehicular traffic removed from the Richmond-San Rafael and Golden Gate Bridges by the patronage of the proposed rapid transit link is important for several reasons. First, it is necessary in order to determine if such a transportation link would attract sufficient patronage to make the project a worthwhile undertaking. Second, it gives an indication of whether enough people would use such a rapid transit route to materially reduce the mounting congestion on the Golden Gate Bridge. Third, it provides a basis for determining the loss of toll revenue which would occur on the Richmond-San Rafael Bridge.

After discussion with the BARTD consultants, procedures were established to determine the volume of traffic which could be expected to be diverted from the Richmond-San Rafael Bridge and the Golden Gate Bridge to the proposed rapid transit facilities. Estimates were made for the years 1965 and 1980. The results of these studies are shown in Tables 6 and 7.

RAPID TRANSIT PATRONAGE

The volume of passengers utilizing a rapid transit line via the Richmond-San Rafael Bridge is shown in Table 8.

This estimated patronage is approximately one third of that predicted for the proposed BARTD line between Marin and San Francisco via the Golden Gate Bridge.

RELIEF OF CONGESTION ON THE GOLDEN GATE BRIDGE

The vehicular traffic diversion from the Golden Gate Bridge is shown on Table 7 to be 4.8 percent of its total traffic for 1965 and 5.7 percent for 1980. These diversions are less than the growth of traffic on that bridge for only one year. Thus, the existence of rapid transit on the Richmond-San Rafael Bridge would delay the time when the Golden Gate Bridge reaches capacity by less than a year.

A comparison between estimated future rapid transit service and existing commuter bus service with respect to travel times between San Rafael and downtown San Francisco is shown below:

Commuter Service: San Rafael-San Francisco

Mode of Travel	Travel Time	One-Way Fare
Rapid Transit	42 Min.	\$0.85(1)
Commuter Bus	47 Min.	\$0.50(2)

The relatively minor decrease in travel time offered by rapid transit combined with the increased cost over existing transit explains the small diversions from the Golden Gate Bridge obtained in this study.

(1) Estimated fare, BARTD proposed fare schedule.

(2) Fare in effect 1/4/65. Authorization for increase is pending.

RICHMOND-SAN RAFAEL BRIDGE REVENUE LOSS

Due to diversion of traffic to rapid transit there would be an estimated annual loss of toll revenue which, at present toll rates, would be $360,000 for the year 1965, increasing yearly to $660,000 for the year 1980.

TABLE 6

AVERAGE DAILY TRAFFIC DIVERSIONS FROM THE RICHMOND-SAN RAFAEL BRIDGE TO RAPID TRANSIT

		1965	1980
Diverted Traffic	Vehicles	1,450	2,700
	Equivalent Passengers	2,610	4,800
Percentage of Total Traffic on Richmond-San Rafael Bridge		11.0%	8.4%

TABLE 7

AVERAGE DAILY TRAFFIC DIVERSIONS FROM THE GOLDEN GATE BRIDGE TO RAPID TRANSIT

		1965	1980
Diverted Traffic	Vehicles	3,090	3,880
	Equivalent Passengers	5,390	6,760
Percentage of Total Traffic on Golden Gate Bridge		4.8%	5.7%

TABLE 8

AVERAGE DAILY RAPID TRANSIT PASSENGERS

	1965	1980
Diverted from the Richmond-San Rafael Bridge	2,610	4,800
Diverted from the Golden Gate Bridge	5,390	6,760
Total	8,000	11,560

VI COST ESTIMATE

The modification of the Richmond-San Rafael Bridge which would be required to accommodate rapid transit includes the following major items of work:

1. Replacement of existing deck system.
2. Strengthening of main trusses.
3. Installation of rapid transit railway facilities.
4. Construction of approach connections.

Only the cost of the work stated in 1. above for Scheme 1 has been estimated and is shown on Table 9 . The determination of the feasibility of strengthening the main truss system would require extensive and detailed studies. In general, the strengthening or renovating of the main supporting members of any long span bridge structure is of doubtful practicality because of the difficulty in deactivating and reinforcing any member without providing extensive temporary supports.

Table 9 shows the cost of replacing the deck only which amounts to approximately one third of the original construction cost for the bridge. The additional cost of items 2, 3, and 4 above would be of major proportions. These cost must be added to the estimate given for item 1 to obtain total project cost.

TABLE 9

COST ESTIMATE

For

ALTERATIONS TO BRIDGE DECK ONLY

To Accommodate Rapid Transit Trains

Truss Spans	$14,100,000
Girder Spans.	3,500,000
Trestle Spans	1,100,000
Subtotal	$18,700,000
Engineering	1,900,000
Contingencies.	2,000,000
Total	$22,600,000

VII LEGAL

LEGAL

The Richmond-San Rafael Bridge was financed and constructed under the provisions of the California Toll Bridge Authority Act (Streets and Highways Code Sections 30000 - 30506). Under the Act, the Authority may authorize the construction of toll bridges, tubes or other toll highway crossings, transportation facilities, and additional transportation facilities (Section 30100), these facilities being defined in Sections 30004 - 30006. The Authority finances such construction by the issuance of revenue bonds (Sections 30200, 30202, 30203).

In authorizing the issuance of revenue bonds, the Authority may include in its bond resolution any agreements with bond purchasers respecting disbursement of bond proceeds as it deems desirable to assure proper application of such funds (Section 30301) and may also include such other provisions for the protection of bond holders as it may approve (Sections 30217, 30221).

By resolution adopted November 7, 1952, (as amended and readopted December 17, 1952), California Toll Bridge Authority authorized the issuance of not to exceed $72,000,000 principal amount of Richmond-San Rafael Bridge Toll Bridge Revenue Bonds. The purposes for which bonds were authorized are stated in the resolution. The installation of rapid transit is not one of the stated purposes. Thus it is not, at this time, legally permissible for California Toll Bridge Authority to finance the installation of rapid transit facilities on the Richmond-San Rafael Bridge. To do so would be a breach of the Authority's contract with its bond holders.

VII CONCLUSIONS

1. Of all the possible arrangements of rapid transit tracks on the bridge, two were considered as possibilities that warranted investigation as to their structural feasibility. The first arrangement called for replacing one lane of highway loading on each deck with rapid transit trains. The second retained the full width of the existing decks for motor vehicles, with rapid transit tracks being placed on cantilever beams outside of the existing trusses.

2. Structural analysis of Scheme 1, substitution of rapid transit tracks for a lane of highway traffic on each deck, shows that a number of the truss members would be overstressed up to a maximum of 40 percent. These overstresses result in safety factors below the minimum allowable. Therefore, the operation of trains on the bridge, in this manner, could not be allowed.

3. Structural analysis of Scheme 2, the addition of the rapid transit tracks outside of the trusses, results in overstresses even more extreme than in Scheme 1. Therefore, the operation of trains on the bridge in this manner also would not be allowable.

4. It is estimated that rapid transit trains would divert some 1,450 vehicles per day from the Richmond-San Rafael Bridge in 1965 and 2,700 in 1980. This would result

in an annual loss of toll revenue of $336,000, presently, increasing yearly to $660,000 in 1980.

5. The rapid transit system on the Richmond-San Rafael Bridge would divert an estimated 3,100 vehicles per day from the Golden Gate Bridge in 1965 and 3,880 vehicles per day in 1980. The relief that this diversion would provide is less than the current annual traffic growth.

6. California Toll Bridge Authority, under the terms of its existing bond indenture, cannot finance the installation of rapid transit facilities on the Richmond-San Rafael Bridge.

IX RECOMMENDATION

Due to the overstresses which would be caused in the main supporting members of the bridge, the extreme cost and doubtful practicability of remodeling and the contractual obligations to the outstanding bond holders, it is recommended that the Richmond-San Rafael Bridge not be used for rapid transit purposes.

APPENDIX A

Senate Bill No. 79

CHAPTER 118

An act making an appropriation for a rapid transit study.

[Approved by Governor May 27, 1964. Filed with Secretary of State May 28, 1964.]

The people of the State of California do enact as follows:

SECTION 1. The Department of Public Works shall conduct a study as to the possibility of using the Richmond-San Rafael Bridge for rapid transit purposes in addition to motor vehicle transportation purposes, taking into consideration, among other things, the weight of the rapid transit vehicles to be used and the ability of the bridge to withstand the stresses and strains incident to their movement over the bridge, and shall submit a report on the results of the study, together with its recommendations thereon, to the Legislature not later than the fifth legislative day of the 1965 Regular Session of the Legislature.

SEC. 2. The sum of twelve thousand dollars ($12,000) is hereby appropriated from the Revenue Fund of the San Francisco-Oakland Bay Bridge to the Department of Public Works for expenditure by the department in conducting the study required by Section 1 of this act.

APPENDIX B

The following is an excerpt from Page 89 of:

REGIONAL RAPID TRANSIT

A Report to the San Francisco Bay Area Rapid Transit Commission

1953 - 1955

Parsons, Brinckerhoff, Hall and Macdonald
Engineers, New York

Richmond-San Rafael Bridge

Investigation of the Richmond-San Rafael Bridge has been predicated on the assumption that automotive traffic will require all three lanes of each deck. Therefore, the investigation has been restricted to the problems involved in supporting transit loads outside the trusses. Transit cannot be carried above or below the existing decks because of interference with tower and lateral bracing.

Dual unit stresses were used in the design of this bridge. That is, higher unit stresses (or a lower factor of safety) were permitted for dead loads than for live loads. This is proper on long-span bridges since the dead loads can be accurately predicted whereas the live loads cannot. To reduce the size of the truss members, lightweight concrete was specified on both decks. In the long cantilever spans, a reduced live load was used because of the probability that maximum design vehicles would not be closely spaced over long lengths.

All of these factors reduce the reserve capacity of the bridge. As a result, the investigation of the thirty-six typical 289-foot truss spans indicates unacceptable overstress in certain members if rapid transit were added to the bridge. Accordingly, the bridge must be considered inadequate to withstand the proposed rapid transit loads in addition to the proposed highway loadings.